Renewable Energy Sources Scheduling with Thermal Unit under Uncertainty in Deregulated Power System

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ABSTRACT - **Renewable energy sources are omnipresent freely available, ecological friendly and they are considered as promising power generating sources due to availability and topological benefits for local power generations. Wind and solar energy have become very essential and important in the generation mix as a result of rising energy demand and environmental issues. Solar energy system might be compensate the wind intermittency generation resource due to lesser start up time, lower operating cost and good ramping capabilities. The generation scheduling for wind-solar energy with thermal unit system in deregulated environment, minimize the total thermal fuel cost and maximize the profit of generation companies, subject to many constraints. While performing the generation scheduling problem by Lagrangian relaxation based particle swarm optimization method the hourly load, wind velocity and solar radiation must be forecasted to prevent the errors. The generation scheduling formulations are involved the perspective of a generation company (GENCO). The deregulation environment is one where the generation, transmission and distribution do not depend on each other. To demonstrate the uncertainty in the proposed method the generation scheduling problem is performed in a simplified generation system.**

Keywords – **Deregulated Power Markets, Generation Scheduling, LR-PSO Method, Renewable Energy Sources.**

NOMENCLATURE

i	index for unit
t	index for time period
I	set of units
T	Total number of units
D_t	Load demand in time period t
R_{hot}	Spinning reserve in time period t
S_i	Hot startup cost of unit. i
S_i^{cold}	Cold startup cost of unit. i
P_i^{max}	Maximum generation limits unit i.
P_i^{min}	Minimum generation limits unit i.
Δt_{up}	Maximum ramp-rate of unit
t_i	Minimum up-time of unit. i
t_i^{down}	Minimum down-time of unit. i
p_{it}	Generation unit in time period
u_{it}	Generation schedule of unit in time period
vit	Number of time periods in which unit has been ON or OFF during time period
$v_{w,}$	Forecast wind velocity at hour t
v_1	Cut in speed wind turbine
v_2	Rated wind turbine speed
v_3	Cut out speed wind turbine
$\Psi(v_{w,t})$	Wind-to-energy conversion function for wind power generation.
P_{wn}	Rated power output for wind power generation
P_{pv}	Solar radiation-to-energy conversion
G_t	Solar radiation at time t
G_{std}	Solar radiation in the standard environment set as $1000W/m^2$
R_c	A certain radiation point set as 150 W/m2
P_{sn}	Rated power output of the PV generator
UCP	Unit commitment problem

LR Lagrange relaxation
PSO Particle swarm optimization

I. INTRODUCTION

Renewable energy, such as wind energy is one of the most promising alternative energy technologies of the future. Throughout recent years, the amount of energy produced by wind-driven turbines has increased exponentially due to significant breakthroughs in turbine technologies, making wind power economically compatible with conventional sources of energy. Wind energy is a clean and renewable source of power and it offers many advantages compared to other energy sources due to two main reasons if cleanliness and abundance. Solar power is worth considering for it's sustainable, renewable and emissions reducing qualities [1], [9].

This paper considers renewable energy generating sources schedule connected to a power system to minimize the total thermal fuel cost and maximize the profit in deregulated environment. The optimization problem in which the total operating cost over the study period is minimized subject to the load demands and small system constraints [2]. The main objectives of works to obtain with the integration of renewable sources with thermal unit power system.

The Lagrange relaxation and particle swarm optimization method is used in this paper to solve the generation scheduling problem considering wind and solar energy systems [3],[12]. To perform the generation scheduling problem using conventional methods, the hourly load for the power balance equations, Wind velocity for the wind power generation, and solar radiation for photovoltaic (PV) generators must be forecasted [10]. Lagrange relaxation and particle swarm optimization (LR-PSO) method to reach the described generation schedules based on certain load demand, wind velocity and solar radiation. To reach the minimum fuel cost generation schedule under Lagrange relaxation and particle swarm optimization in deregulated environment, the total fuel cost, load demand, wind velocity and solar radiation are expressed in lambda (λ), Pbest and G_{best} notations.

Although methods such as dynamic programming and mixed integer programming can theoretically obtain the feasible (or near feasible) solution, they required an impractical computation time for a large scale unit commitment problem (UCP). The LR-PSO method basically solves the dual problem of the UCP. The objective function of the dual problem is represented as the optimal value of the LR problem [4], which can be decomposed into small sub problems P_{best} and G_{best} of each unit. Using these characteristics the dual solution of the UCP can be obtained efficiently even if the problem size is large.

In this paper, the generation scheduling problem with system constraints of individual units are considered. Moreover, a reasonable solution of long term UCP with renewable energy is important for estimating of the validity of a price in electricity markets [5], in particular, deregulated market where dominant electric power companies exist. Since the long term UCP becomes an uncertainty UCP, the LR-PSO method is applied in this work.

II. PROBLEM FORMULATION

The objective function of the renewable energy sources generation scheduling problem represents the unit commitment problem (UCP) is to determine the schedule and production amount of generating units within a power system subject to machine and operating constraints [6]. The total production cost consists of the fuel cost and start up cost.

$$TotalCost = [\sum_{t=1}^{T}\sum_{i=1}^{I} Fc_i(P_{i,t}) + \text{Startup cost}_{i,t}]U_i^t \quad (1)$$

The fuel cost unit i in the time period t is usually given as the following function of p_{it}.

$$Fc_i(P_i) = a_i + b_i P_i + c_i P_i^2 \quad (2)$$

Where,

A_i, B_i and C_i are constants and are nonnegative.

The thermal unit startup cost is related to the energy necessary to turn ON a unit that has been OFF and occurs only when the units is turned ON during time period t ($u_{i,t}$-1=0 and u_{it}=1). In general the startup cost depends on the number of time periods that the unit has been turned OFF. The constraints of the conventional energy generation scheduling consist of the system constraints which are as follows.

***System Constraints*:**

1) Demand constraints

$$D_t = \sum_{i=1}^{n} u_{it}, p_{it} \quad t=1,\ldots,T \quad (3)$$

2) Spinning reserve constraints

$$D_t + R_t \le \sum_{i=1}^{n} u_{it}, p_i^{max} \quad ,t=1,\dots,T \qquad (4)$$

The spinning reserve constraint is used in the case of an unexpected load demand or a unit failure.

Thermal Unit Constraints:

1) Generation limit constraints
$$U_{it}, P_i^{min} \le P_{it} \le P_i^{max}, \quad t=1,\dots,T \qquad (5)$$
2) Minimum uptime constraints
$$U_{it} = 1\ if\ 1 \le V_{it-1} < t_i^{up}, \quad t=1,\dots,T \qquad (6)$$
3) Minimum downtime constraints
$$U_{it} = 0\ if\ -1 \ge 1V_{it-1} > -t_i^{down}, t=1,\dots,T \qquad (7)$$
4) Ramp constraints
$$P_{it} - u_{it}, P_{it-1} \le \Delta_i, \quad t=1,\dots,T \qquad (8)$$

The minimum uptime (downtime) constraints mean that a unit must be ON (OFF) for a certain number of time periods once it has been turned on (off). The ramp constraints mean the generation not sudden change one state to other state quickly.

Wind Units Constraints:

1) Total available wind generation

$$P_{wt}(t) = \sum_{j=1}^{Nw} P_{wj}(t) \qquad (9)$$

2) Power output limits on wind energy system

$$P_{w,t} = \begin{cases} 0 & V_{w,t} \le V_1 \text{ or } V_{w,t} \ge V_3 \\ \Psi(V_{w,t}) & V_1 \le V_{w,t} \le V_2 \\ P_{wr} & V_2 \le V_{w,t} \le V_3 \end{cases} \quad t=1,2\dots,T \qquad (10)$$

3) Total actual wind generation limit

$$0 \le P_{wt}(t) \le P_{wt}(t)$$

$$P_{pv}(G_t) = \begin{cases} P_{sn}\dfrac{(G_t)^2}{G_{std} R_c} & 0 < G_t < R_c \\ P_{sn}\dfrac{G_t}{G_{std}} & G_t > R_c \end{cases} \qquad (12)$$

2) Power output limits on solar energy system

$$P_{pv}(G_t) - P_{b,t} - P_{s,t} = 0$$
$$|P_{b,t}| \le P_b^{max} \qquad t=1,2\dots.T \qquad (13)$$
$$|P_{s,t}| \le P_s^{max}$$

III. GENERATION SCHEDULING BY PROPOSED METHOD

The LR-PSO method solves the dual problem of the UCP. The generation scheduling in dual problem has two kinds of constraints: minimum up, minimum down time constraints and coupling constraints. Then, from the duality theory the co-ordinate min (P) ≥ max(D).

Now has been considered Lagrange function L is defined as

$$L(p,u,\lambda,u) = \phi(p,u) + \sum_{t=1}^{T} \lambda_t (D_t - \sum_{i=1} u_{it}, p_{it}) + \sum_{t=1}^{T} \mu_t (D_t + R_t - \sum_{j=1} u_{it}, p_i^{max}) \qquad (14)$$

In general there exists dual problem P_{best} and G_{best} for the generation scheduling if Φ (p, u) – θ (λ,M) is small for given feasible solutions (p,u) and (λ,μ) of P and D, respectively, then (p,u) is a feasible solution of P. Thus, (λ,μ) to be the maximum solution of D.

The PSO approach has some similarities to LR and evolutionary algorithms. PSO has a population of individuals

Solar Unit Constraints:

1) Total power generation (11)

that move through the D- dimensional search space and each individual has a velocity that acts as an operator to obtain a new set of individuals. Individuals, called particles, adjust their movements depending on both their own experience and the population's experience. A each iteration, a particle moves towards a direction computed from the P_{best} visited position and the G_{best} visited position of all particles in its neighborhood.

The dual problem D is no differentiable convex problem. In order to solve such a problem the sub gradient method and the bundled method are useful. It is reported that the bundled method requires fewer iterations to converge, as compared to the sub gradient method [7]. Since the cost of solving the dynamic programming problem is much greater than that of solving the Lagrange relaxed problem the effect of the reduced number of iterations of the bundled method is limited. Therefore in this paper apply LR-PSO method to solve dual problem.

$$Min = \sum_{t=1} [u_{it} \{ f(p_{it}) - \lambda_t , p_{it} (u_i)] - \mu_i \, p^{max}_{it} \} + s_i$$

$$s, u(p_i, u_i) \notin u_i \quad (15)$$

In this paper assume that startup cost function S_{it} consists of two steps of S_i^{hot} and S_i^{cold} , for simplicity. Here S_i^{hot} represents the "hot startup cost ," which is once unit commit to turn OFF back to turn ON time periods the unit has been OFF is below (t_i^{down} $+t_i^{cold}$). S_i^{cold} represents the "cold startup cost," which is once unit commit to turn ON back to OFF (when the number of $-v_{it}$ of time periods the unit has been OFF is greater than $t_i^{down}+t_i^{cold}$). The startup cost S_{it} (u) of unit i in time period t is then represented as.

$$s_{it}(u) = \begin{cases} U_{it}(1-V_{i,t-1})s_i^{hot}, if \ V_{i,t-1} \le -t_i^{down} - t_i^{cold} \\ U_{it}(1-u_{i,t-1})s_i^{cold}, if \ V_{i,t-1} \ge -t_i^{down} - t_i^{cold} \end{cases} \quad (16)$$

Algorithm Steps for LR Based PSO Method

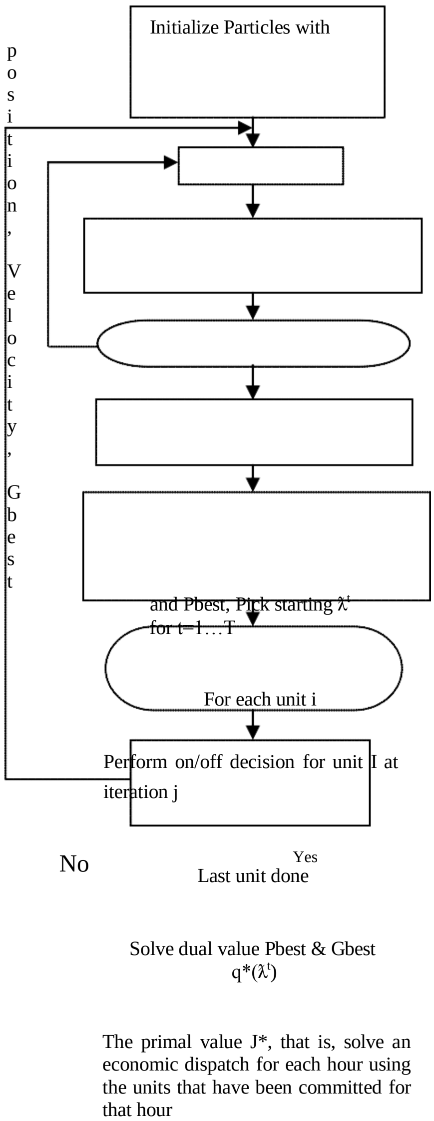
Step:1 Initialize with the constraints for the objective function.

Step:2 Data input, initialize Lagrangian multipliers and L.

Step:6 Converge test: if the duality gap within specified limit? If yes go to step 8, if no go to step 7.

Step:7 Take the Gbest values and corresponding generation scheduling for cost optimization.

Step:8 optimal output .



Step:3 For the given set of multipliers, Generate the population, P_{best} and G_{best} value. solve the unit dual problem, eq. (3) for i=1,2,.,n.. Calculate dual criterion TC,eq.(4), and store Fi if Fi is increased.

Steb:4 Feasibility test; If the dual solution is primal feasible go to step 5. If no, update multipliers according to sub gradients, eq. (14), (15), (16) and go to step 2:

Step:5 Primal feasible solution. Perform emission constrained dispatch to find power outputs and marginal costs. Calculate primal objective.

Calculate the relative duality gap Pbest and Gbest

Update λ^t for all t and perform local random search

No

Fig. 1 Flow chart for LR-PSO method

A flow chart for minimization of total fuel cost and maximizes the profit for generation scheduling with renewable energy shown in fig. 1. The load demand [D (t) + P_{th} (t) + P_{pv} (t) + P_{wind} (t)] is met from conventional running units of the schedule [I_1 (t), I_2 (t)… I_N (t)] ^{T} with dispatch computed using lambda iteration.

IV. COMPUTATIONAL RESULTS

The system comprises sixteen thermal units, one equivalent wind energy system and one equivalent solar energy system. The cost function data for the sixteen thermal units are given in Table II. The forecast total the forecast solar radiation and wind velocity data are shown in Table I. The spinning reserve requirement is set to 5% of the load demand.

Case 1: Only the thermal generating system is used to supply load demands.
Case 2: Thermal and solar energy generating systems are connected to supply load demands.
Case 3: Thermal, solar and wind generating systems are connected to supply load demands.

TABLE I
FORECAST SOLAR RADIATION AND WIND VELOCITY

Time in hour	1	2	3	4	5	6
G_t (w/m^2)	0	0	0	0	0	0
$V_{w,t}$ (m/s)	3.5	3.6	1.5	1.4	0.1	1.8
Time in hour	7	8	9	10	11	12
G_t (w/m^2)	111	311	375	503	617	686
$V_{w,t}$ (m/s)	1.3	2.2	3.8	3.7	2.0	0.6
Time in hour	13	14	15	16	17	18
G_t (w/m^2)	703	736	586	425	291	86
$V_{w,t}$ (m/s)	0.4	8.4	9.9	10.1	9.7	9.2
Time in hour	19	20	21	22	23	24
G_t (w/m^2)	0	0	0	0	0	0
$V_{w,t}$ (m/s)	9.6	10	10	9.5	9.9	12.6
Solar form size = 60 MW Wind form size = 40 MW (20 wind turbines and 2 MW each)						

In case 1, only the thermal generating system (sixteen thermal units) is employed to supply load demands which are forecasted. There are always errors in these forecast loads. Therefore, the Lagrange relaxation based particle swarm optimization method is used to solve the generation scheduling problem. The total thermal power output and forecast hourly load. That the total thermal generation meets the load demands.

In case 2, the generation system that includes sixteen thermal units, and one equivalent solar energy system is used to supply the load demands. The solar power included in sixth hour to generate the maximum level of photovoltaic cells. In this case the load demands, solar radiation for PV generator are forecast. There are always errors in these forecast values. Therefore, the LR-PSO method is used to solve the problem.

In case 3, the generation system that includes thermal, solar and wind generating units is used to supply load demands. The proposed method is employed to solve the problem. That includes sixteen thermal units, one equivalent solar energy system, and one equivalent wind energy system. In this case the load demands, total thermal units, wind velocity for wind turbine generator and solar radiation for PV generator is forecast.

In above generation scheduling process, first hour to sixth hour thermal unit only satisfy the load demand. In that period wind and solar units are not available to satisfy the demand. The next 12 hours solar unit also committed to the thermal unit for satisfying the demand. Wind unit also committed in the period of 13th to 18th hours.

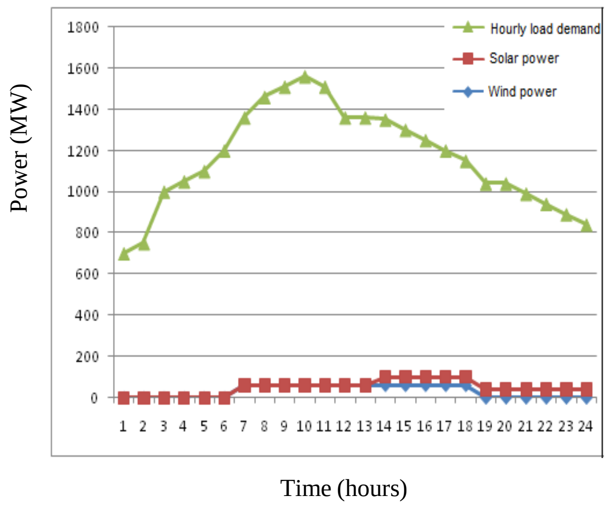


Fig.2 Total load demand, solar and wind energy power output

In this period thermal, solar and wind are scheduled to satisfy the demand. Due to the commitment of renewable energy the fuel cost for thermal unit is drastically reduced. For 18th to 24th hours thermal and wind unit is operated to obtain the load demand solar unit is not available in that period. The

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same load demand for 2nd and 3rd hour at the time thermal unit only generate power to supply 24th hour the same load demand at the time thermal and wind power generate to supply the load demand. By including the renewable energy in generation scheduling process the total cost is reduced and the profit is maximized.

TABLE II
SIXTEEN UNIT THERMAL SYSTEM DATA

Unit	P_{max} (MW)	P_{min} (MW)	A_i (Rs/MW^{2}h)	B_i (Rs/MWh)	C_i (Rs/Hr)	Min^{up} (Hr)	Min^{down} (Hr)	$Cold^{cost}$ (Rs/Hr)	Hot^{cost} (Rs/Hr)	Cost/Hr	Initial state
1	50	12.5	15.4	1280	35	48	48	50	48	2	-5
2	50	12.5	15.4	1280	35	48	48	50	48	2	-5
3	50	12.5	15.4	1280	35	48	48	50	48	3	-7
4	100	25	11.2	1330	85	48	48	250	48	3	-3
5	100	25	8.5	1650	80	48	48	150	48	3	-8
6	100	25	9.0	1680	85	14	10	250	-10	3	-8
7	100	25	9.0	1680	85	14	10	250	-10	3	-10
8	100	25	9.0	1680	85	14	10	250	-10	3	-24
9	200	50	4.3	1650	170	14	10	300	-10	2	-1
10	200	50	4.3	1650	170	14	10	300	-10	2	-24
11	300	75	10.2	2850	915	14	10	1800	-10	2	24
12	300	75	10.4	2890	935	14	10	1800	-10	3	-24
13	300	75	10.4	2770	935	14	10	1800	-10	-1	-24
14	400	100	7.4	2780	1180	14	10	2700	-10	-1	24
15	400	100	7.4	1640	1185	14	10	2700	-10	-1	-24
16	400	100	2.1	2870	335	48	48	750	48	-1	-24

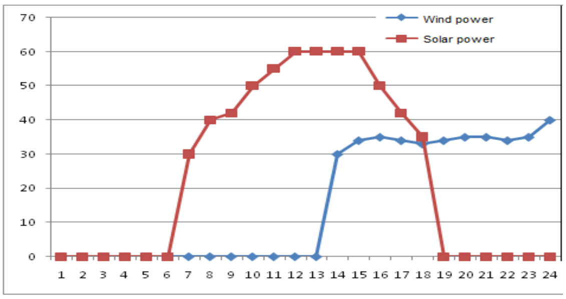
TABLE III
OPERATING STATUS FOR 18 UNITS THERMAL, WIND AND SOLAR ENERGY SYSTEM

Time (H)	Load Demand (MW)	U-1	U-2	U-3	U-4	U-5	U-6	U-7	U-8	U-9	U-10	U-11	U-12	U-13	U-14	U-15	U-16	U-17	U-18	Fuel Cost (Rs/Hr)

1	900	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	135050.0
2	850	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	138580.0
3	850	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0	138580.0
4	950	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0	140642.0
5	1000	0	0	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0	146874.0
6	1100	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	0	149653.0
7	1150	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	0	1	152212.0
8	1200	1	1	1	1	0	0	0	0	1	0	1	0	0	1	0	0	0	1	153215.0
9	1300	1	1	1	1	1	1	0	0	1	0	1	0	0	1	0	0	0	1	158565.0
10	1400	1	1	1	1	1	1	0	0	1	0	1	0	0	1	0	0	0	1	165461.0
11	1450	1	1	1	1	1	1	1	0	1	0	1	0	0	1	0	0	0	1	166896.0
12	1500	1	1	1	1	1	1	1	0	1	0	1	0	0	1	0	0	0	1	172314.0
13	1400	1	1	0	1	1	1	0	0	1	0	1	0	0	1	0	0	1	1	165461.0
14	1300	1	1	0	1	1	0	0	0	1	0	1	0	0	1	0	0	1	1	157866.0
15	1200	1	1	0	1	0	0	0	0	1	0	1	0	0	1	0	0	1	1	152145.0
16	1050	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	1	149296.0
17	1000	1	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	1	145114.0
18	1100	1	1	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	1	149532.0
19	1190	1	1	1	1	0	0	0	0	1	0	1	0	0	1	0	0	1	0	152445.0
20	1390	1	1	1	1	1	1	0	0	1	0	1	0	0	1	0	0	1	0	163645.0
21	1290	1	1	1	1	1	0	0	0	1	0	1	0	0	1	0	0	1	0	156737.0
22	1090	1	1	1	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	148189.0
23	900	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	139264.0
24	850	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	0	137734.0

Solar form size = 60 MW Wind form size = 40 MW (20 wind turbines and 2 MW each)

Power (MW)



Time (hour)

Fig.3 Total wind and solar power output

V. Conclusion

Generation scheduling with renewable energy sources under uncertainty has been presented in this paper to illustrate cost minimization and profit maximization. Lagrangian relaxation based particle swarm optimization has been used to generate a feasible schedule considering the uncertainties of wind and solar energy. To demonstrate the effectiveness of the proposed LR based PSO method, the IEEE-16 unit thermal systems with one unit equivalent wind energy and one unit equivalent solar energy systems were performed. The results revealed that the proposed LR based PSO method is very effective in reaching a proper UCP when imprecision in load demands, wind speed and solar radiation is considered. The proposed method has good performance and ability to obtain the solution of generation scheduling problem.

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Biography

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